MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2016/2017

EME4076 – MECHANICAL VIBRATIONS

(All sections)

04 MARCH 2017
02:30 p.m. – 04:30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 9 pages including cover page with 5 Questions and 3 appendices.

2. Attempt **FOUR** out of **FIVE** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

Question 1

Figure Q1 shows a 50-kg electrical motor mounted at the middle of a steel plate. The dimensions of the plate are 1.25 cm in thickness, 50 cm in width and 250 cm in length. The plate is clamped to the support along its two sides of the width. A disk D with mass of 3.5 kg is mounted eccentrically from the axis of rotation of the motor. Knowing that the modulus of elasticity E and damping ratio ζ of the plate are 200×10^9 N/m² and 0.05, respectively. From the operation, the system is found to vibrate with a deflection of 1 cm at resonance.

(a) Determine the radial location (eccentricity e) of the unbalanced mass.

[5 marks]

(b) Find the smallest possible amplitude of vibration of the plate that can be obtained if the motor is operated at rotation speed that is much larger than resonance.

[5 marks]

(c) Determine the peak deflection of the system that can occur, and the rotation speed ω of the motor at which it will occur.

[9 marks]

(d) Determine additional mass to be added to the base of the motor such that the peak deflection of the system is reduced by 10 times and then comments the answer.

[6 marks]

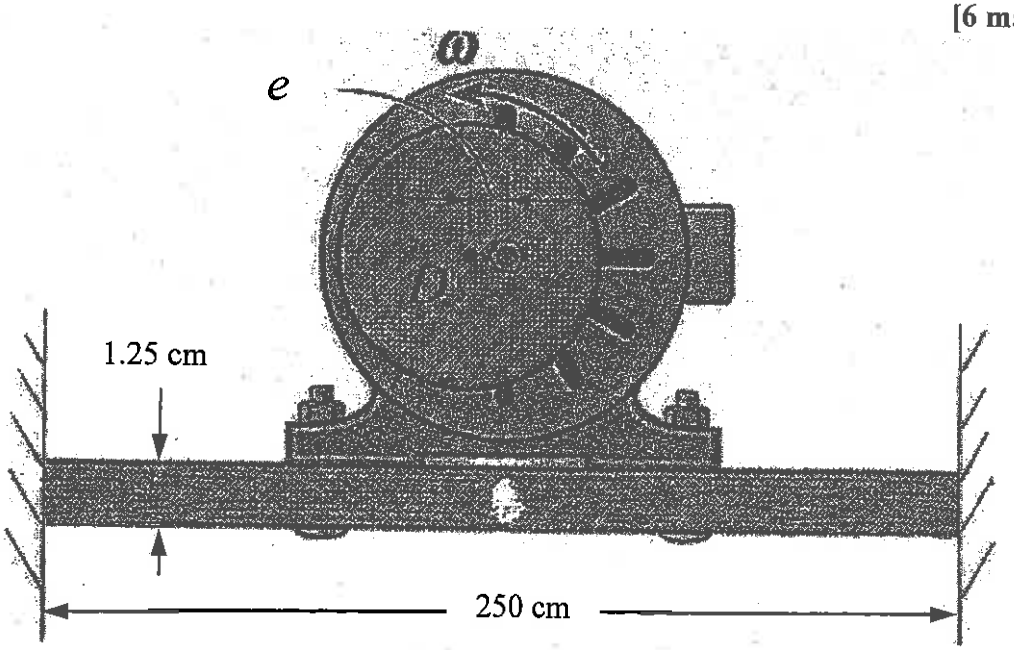


Figure Q1

Continued .....

Question 2

A 20-kg delicate apparatus is to be mounted to a table that is bolted to the floor in a laboratory. Manufacturing data indicated that in order for the apparatus to operate properly, the acceleration felt by the apparatus should be less than 4 m/s². To protect the apparatus from the vibration from the table, an undamped isolator is placed between the apparatus and the table.

(a) Measurements indicate that due to the operation of a nearby pump of a factory that operates at 2000 rpm, the table has a peak component of vibration of 0.25 mm. What is the maximum stiffness of an undamped isolator should be such that the apparatus will operate properly?

[12 marks]

(b) Due to business expansion, a sewing machine was bought and installed in the factory. This machine will cause the table to vibrate at an amplitude of 0.4 mm when operated at 2500 rpm. If the pump of part (a) and the sewing machine are operated simultaneously in the factory, and the isolator of part (a) is used to place between the table and the apparatus, determine how much mass needed to add to the apparatus in order for it to function properly.

[13 marks]

Continued .....

Question 3

A box with a mass m_1 contains a bowling ball (a sphere) with a mass m_2. It has a radius of r. Packing supports the ball at the top and bottom, but unfortunately, the box is on its side as shown in Figure Q3. The packing is elastic with a modulus of k. Given that the ball rolls without slipping in the box. As shown in the figure, a harmonic force $F(t)$ is applied to the outer case of the packaging system. If $m_1 = 5\,\text{kg}$, $m_2 = 7\,\text{kg}$, $r = 100\,\text{mm}$, and $k = 1200\,\text{N/m}$,

(a) derive the equation of motion of the system in terms of x_1, the displacement of the box, and x_2, the displacement of the ball center. Find the natural frequencies of the box and the ball and sketch the mode shapes, and

[15 marks]

(b) determine the absolute motion of both the ball and the box, if $F(t) = \sin 20t$. What is the maximum compression force on the elastic packaging material?

[10 marks]

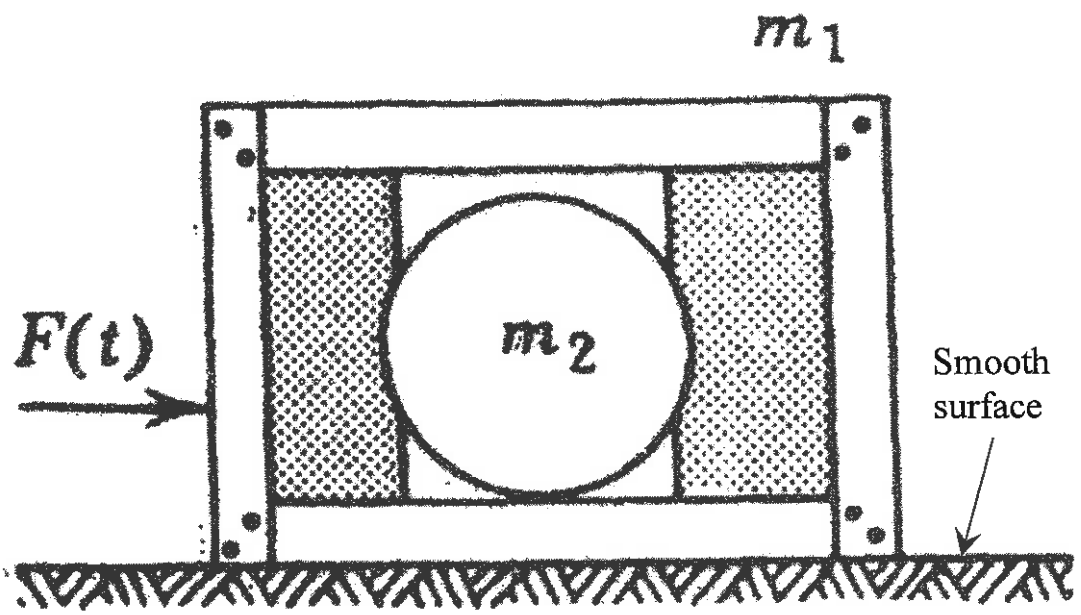


Figure Q3

Continued .....

Question 4

A "bungee jumper" who weighs 720 N ties one end of an elastic rope to a bridge above a river and the other end to himself/herself and leaps from the bridge as shown in Figure Q4. The rope has an unstretched length of 60 m and stiffness of 2 kN/m.

(a) Determine the vibratory motion of the jumper about his/her static equilibrium position.

[15 marks]

(b) Find the maximum tension in the rope.

[3 marks]

(c) If a "free jumper" who is the jumper without rope is jumped from the bridge at the same time as the bungee jumper, determine the distance between the bungee jumper and free jumper 4 s after the jump.

[7 marks]

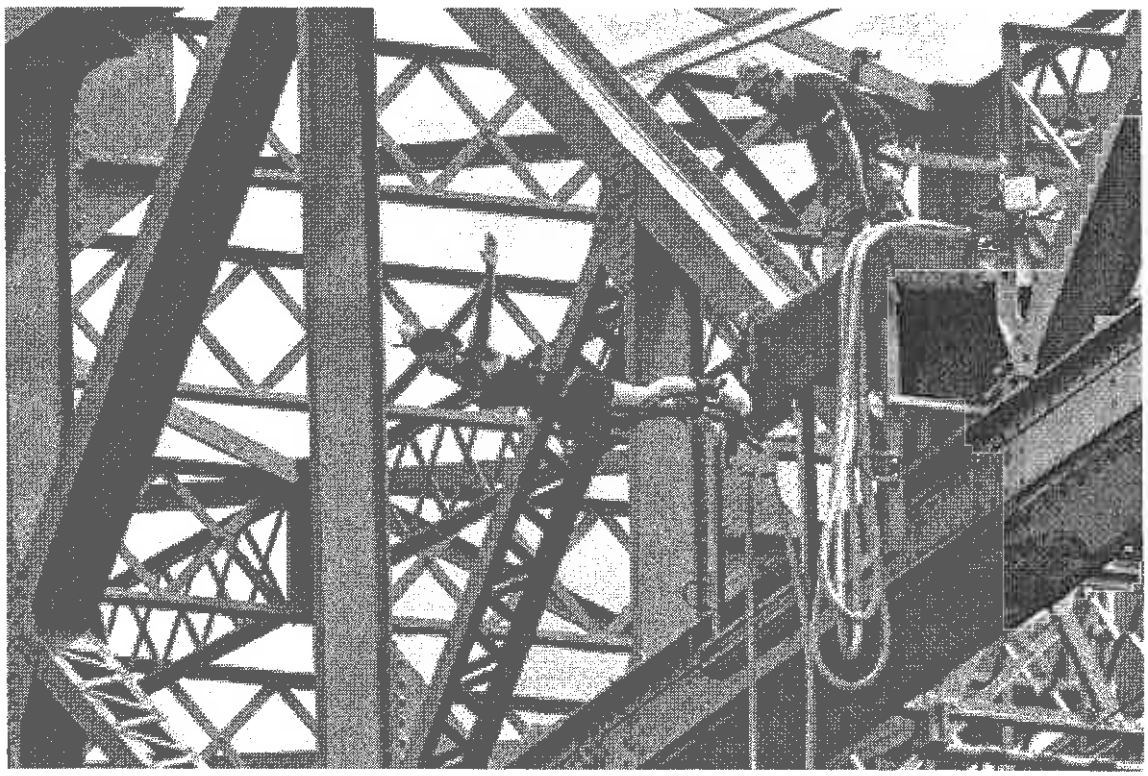


Figure Q4

Continued .....

Question 5

Figure Q5(i) shows two identical pistons, each has mass 2.5 kg, fit in a smooth tube that is 50 mm in diameter. The pistons are elastically connected by a spring with a constant of 2000 N/m. The tube is connected through valve B to a large storage tank A which contains a dry gas stored at a pressure of 100 kPa. At the position shown, the spring is unextended and uncompressed and has a length of 0.25 m, and the pistons are located symmetrically about the tube. At time $t = 0$, the valve B is suddenly opened and the pressure p in the tube rises to the pressure in the storage tank as shown in Figure Q5(ii) which can be described by equation $p = p_s(1 - e^{-at})$ where p_s is the final static pressure, a is a constant and t is time in second.

(a) Determine the response of the system as a function of time.

[15 marks]

(b) Find the steady-state maximum and minimum separation of the piston from the equilibrium.

[10 marks]

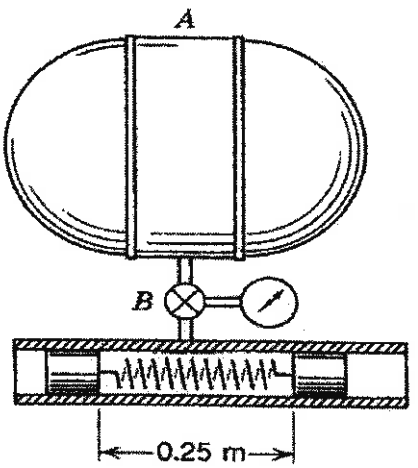


Figure Q5(i)

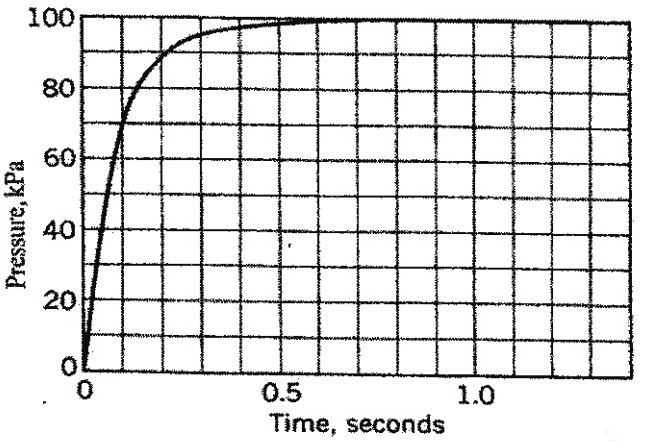


Figure Q5(ii)

Continued .....

Appendix 1

Vibrations

Equations of Motion

$$m\ddot{x} + c\dot{x} + kx = F_0 \sin \omega t$$

General Solution

$$x(t) = x_c(t) + x_p(t)$$

$$x_p(t) = D \sin(\omega t - \varphi)$$

$$D = \frac{F_0/k}{\sqrt{[1-r^2]^2 + (2\zeta r)^2}} \qquad where \quad r = \frac{\omega}{\omega_n}$$

$$\varphi = \tan^{-1} \frac{2\zeta r}{1-r^2}$$

$$x_c(t) = D_1 e^{\lambda_1 t} + D_2 e^{\lambda_2 t} \qquad \zeta > 1$$

$$x_c(t) = (B + Ct) e^{-\omega_n t} \qquad \zeta = 1$$

$$x_c(t) = e^{-\zeta \omega_n t} (B \cos \omega_d t + C \sin \omega_d t) \qquad \zeta < 1$$

$$\omega_n = \sqrt{k/m} = 2\pi f_n, \qquad f_n = \frac{1}{\tau_n} = \frac{\omega_n}{2\pi}$$

$$\zeta = \frac{c}{2m\omega_n}$$

$$\lambda_{1,2} = -\zeta \omega_n \pm \omega_n \sqrt{\zeta^2 - 1} \qquad \zeta \geq 1$$

$$\omega_d = \omega_n \sqrt{1-\zeta^2} \qquad \zeta < 1$$

Force and Displacement Transmissibility

$$\frac{F_T}{F_0} = \frac{X}{Y} = \left[\frac{1 + (2\zeta r)^2}{(1-r^2)^2 + (2\zeta r)^2}\right]^{\frac{1}{2}}$$

Rotating Unbalance: Amplitude of Response

$$X = \frac{m_0 e}{m + m_0} \frac{r^2}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}}$$

Fourier's series

$$x(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos n\omega t + b_n \sin n\omega t]$$

$$a_n = \frac{2}{\tau}\int_0^{\tau} x(t) \cos n\omega t \, dt \qquad b_n = \frac{2}{\tau}\int_0^{\tau} x(t) \sin n\omega t \, dt$$

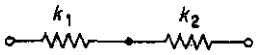
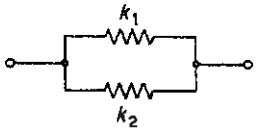
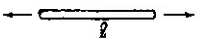
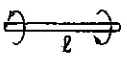
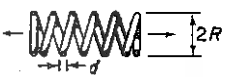
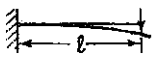
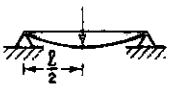
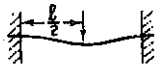
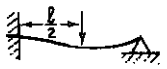
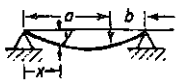
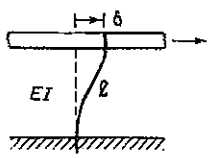
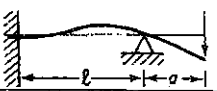
Unit response function (underdamped)

$$h(t-\tau) = \frac{e^{-\xi\omega_n(t-\tau)}}{m\omega_d} \sin \omega_d (t-\tau)$$

Continued .....

Appendix 2

Table of Spring Stiffness

	$k = \frac{1}{1/k_1 + 1/k_2}$	
	$k = k_1 + k_2$	
	$k = \frac{EI}{l}$	l = moment of inertia of cross-sectional area l = total length
	$k = \frac{EA}{l}$	A = cross-sectional area
	$k = \frac{GJ}{l}$	J = torsion constant of cross section
	$k = \frac{Gd^4}{64nR^3}$	n = number of turns
	$k = \frac{3EI}{l^3}$	k at position of load
	$k = \frac{48EI}{l^3}$	
	$k = \frac{192EI}{l^3}$	
	$k = \frac{768EI}{7l^3}$	
	$k = \frac{3EIl}{a^2b^2}$	$y_x = \frac{Pbx}{6EIl}(l^2 - x^2 - b^2)$
	$k = \frac{12EI}{l^3}$	
	$k = \frac{3EI}{(l+a)a^2}$	
	$k = \frac{24EI}{a^2(3l+8a)}$	

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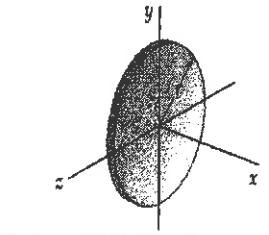
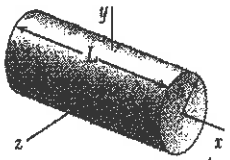
Appendix 3: Mass Moment of Inertia of Homogenous Solids



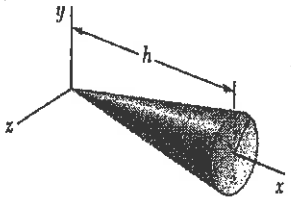
$I_x = \frac{1}{2}mr^2$

$I_y = I_z = \frac{1}{4}mr^2$



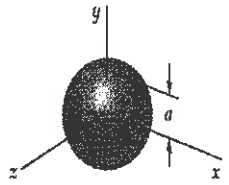
$I_x = \frac{1}{2}ma^2$

$I_y = I_z = \frac{1}{12}m(3a^2 + L^2)$

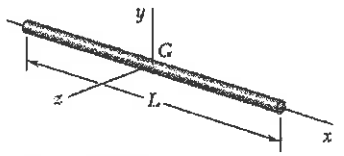


$I_x = \frac{3}{10}ma^2$

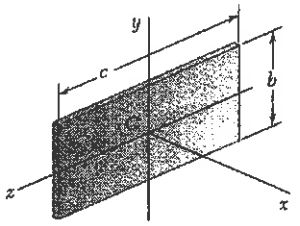
$I_y = I_z = \frac{3}{5}m(\frac{1}{4}a^2 + h^2)$



$I_x = I_y = I_z = \frac{2}{5}ma^2$



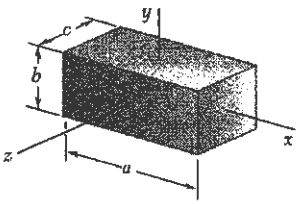
$I_y = I_z = \frac{1}{12}mL^2$



$I_x = \frac{1}{12}m(b^2 + c^2)$

$I_y = \frac{1}{12}mc^2$

$I_z = \frac{1}{12}mb^2$



$I_x = \frac{1}{12}m(b^2 + c^2)$

$I_y = \frac{1}{12}m(c^2 + a^2)$

$I_z = \frac{1}{12}m(a^2 + b^2)$

End of Paper